Effects of Type and Strength of Force Feedback on Movement Time in a Target Selection Task

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NextGen Flight Decks

- Future flight decks will require advanced onboard avionics
  - *E.g., the Cockpit Display of Traffic Information (or CDTI)*
    - Allows pilots to view surrounding airspace and manipulate routes in real time
    - Would require direct interaction from the pilot (e.g., item selection)
  - *There will be constraints on the implementation of these new tools onto the flight deck:*
    - The limited space in the cockpit will necessitate small interfaces
    - The instability of the cockpit will make traditional HCI input devices unlikely (e.g., mouse, touch screen)

Force Feedback

- Additional technologies may be necessary to ensure optimal performance
  - *Force feedback has been found to enhance performance in difficult HCI tasks (Griffiths and Gillespie, 2005)*
    - Force feedback works to actively **assist** or **resist** operator movement during a task (e.g., target selection)
      - An attractive or repulsive force will help pull or push an operator's selection tool towards or away from a given target
      - Attractive forms of force feedback are commonly referred to as "virtual fixtures" or "gravity wells"
  - *According to Ahlstrom (2005), force feedback reduces:*
    - Task completion times
    - Operator musculoskeletal discomfort
    - Error rates

Force Feedback

- Akamatsu & MacKenzie (1996) and Hwang et al. (2003) divided target selection tasks into 2 primary components:
  - *Approach Time & Selection Time*
    - Akamatsu and MacKenzie found that force feedback reduced Selection Time
      - Used a friction-based force feedback (only engaged once inside target)
    - Hwang et al. found that force feedback reduced Approach Time
      - Used an attractive force feedback (engaged before reaching target)
  - *Neither study manipulated the strength or type of force feedback*

Force Feedback

- Rorie et al. (2012) examined the effect of force feedback and movement direction on overall movement time
  - *Presented targets on a CDTI-like display*
  - *Manipulated direction, size and distance of target*
    - The presence of force feedback was found to disproportionately improve the selection of small and close targets
      - Overall, force feedback reduced target selection times by 47%
  - *Only 1 level and type of force feedback was utilized*

Force Feedback

- Little research has been done to study the optimal *level* of force feedback for a given task
  - *I.e., what's the ideal strength of the attractive or repulsive force?*
- The primary criticism of the implementation of force feedback is the effect of "distractors"
  - *Therefore, the goal should be to find the lowest level of force feedback that produces greatest benefits*

Purpose

- To examine the effect of **multiple** *levels* and *types* of force feedback in a CDTI display environment
  - *Extension of Rorie et al. (2012):*
    - Examines multiple levels of two different types of force feedback:
      - Gravitational Force Feedback
        - Acts as an attractive force that pulls participant's cursor towards the target when outside of it
      - Spring Force Feedback
        - Acts a rubber band-type force that makes it hard to leave the target once the participant is inside
    - Applies Akamatsu and MacKenzie's (1996) movement time components:
      - Approach Time
      - Time in Target

Method

- Subjects
  - *12 participants (7 female, 5 male; M = 25.83 years old) from NASA Ames and San Jose State University*
    - Right handed, normal or corrected-to-normal vision
- Apparatus
  - *Standard Logitech laser mouse*
  - *Novint Falcon force feedback device*
    - 4” x 4” x 4” operational workspace
    - Capable of providing up to 2lbs of force

Method

- Two force feedback models:
  - *(Modified) Newton's Gravitational Law Model:*
    - $F = \{K_1 / ||d||^2\}\ \hat{d}$ (when $||d|| > r$)
      - K_1 units = Newtons Pixels^2 (NPS)
    - *3 Gain Levels of Gravitational Force Feedback Used*
      - K_1 = 100 NPS, 300 NPS, & 500 NPS
  - *Spring Force Model:*
    - $F = \{K_2 * ||d||\}\ \hat{d}$ (when $||d|| \leq r$)
      - K_2 units = Newtons Per Pixel (NP)
    - *2 Gain Levels of Spring Force Feedback Used*
      - K_2 = 0.1 NP & 0.3 NP

Method

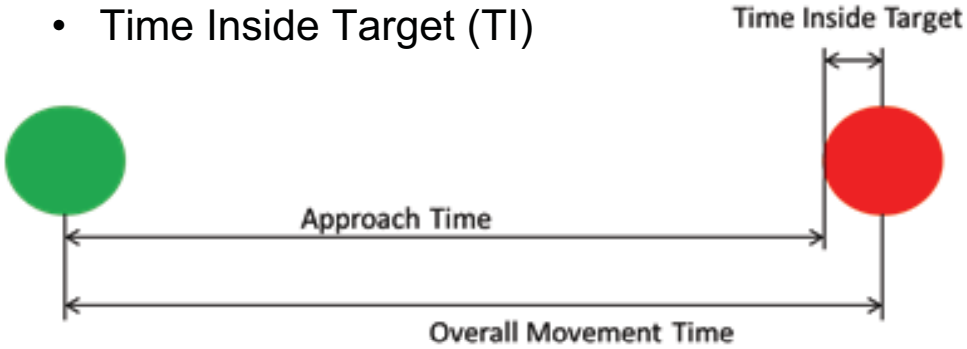
- 2 x 2 x 2 x 3 x 12 Within-Subjects Design
  - *144 trials (i.e., target selections) per experimental block*
    - 20 experimental blocks with the Novint Falcon
    - 2 experimental blocks with Mouse

    = 3,168 total target selections per participant

Independent Variable	Levels
Target Size	0.5cm & 1cm
Target Distance	3.5cm & 8.5cm
Spring Force Level	0.1 NP & 0.3 NP
Gravitational Force Level	100 NPS, 300 NPS & 500 NPS
Target Direction	0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, & 330°

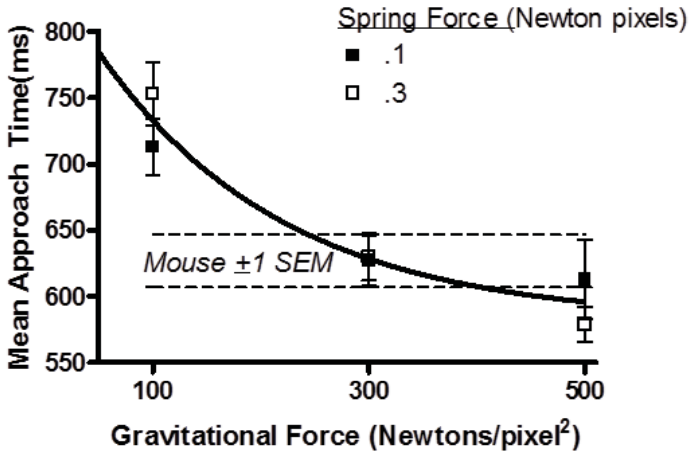
Method

- Procedure
  - *Point-and-Click task*
    - Start icon remained constant size (0.75cm) and location (center)
    - All independent variables were manipulated randomly within each experimental trial
  - *Dependent Variables*
    - Overall Movement Time (ms)
      - Approach Time (AT)
      - Time Inside Target (TI)



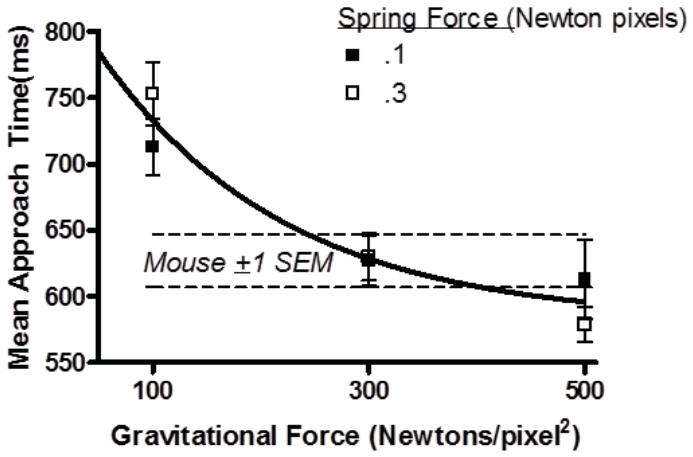
Results

- Approach Time
  - *Main Effect of Gravitational Force Level*
    - 300 & 500 NPS both resulted in significantly faster approach times than the 100 NPS Gravitational Force Level
  - *Gravitational Force X Spring Force*
    - 0.3 NP Spring Force Level only had an effect at the lowest Gravitational Force Level



Results

- Approach Time
  - *Main Effect of Target Distance*
    - Smaller approach times for closer targets
  - *Compared to performance with the mouse:*
    - 100 NPS significantly worse
    - 300 and 500 NPS Gravitational Force Levels were equal or better



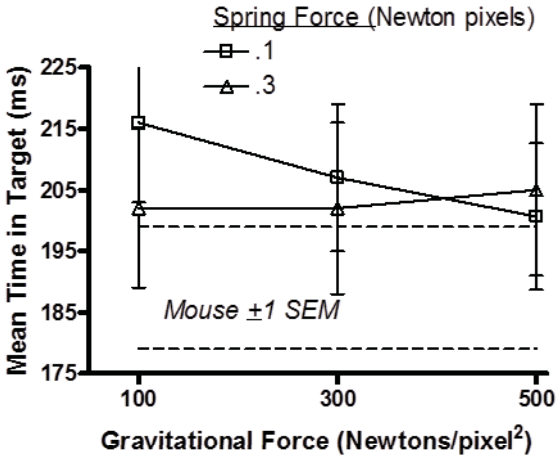
Results

- Time in Target
  - *Main Effect of Spring Force Level*
    - The 0.3 NP Spring Force Level led to significantly less time spent inside the target than the 0.1 Spring Force Level
  - *No Main Effect of Gravitational Force Level, Target Distance or Target Size*

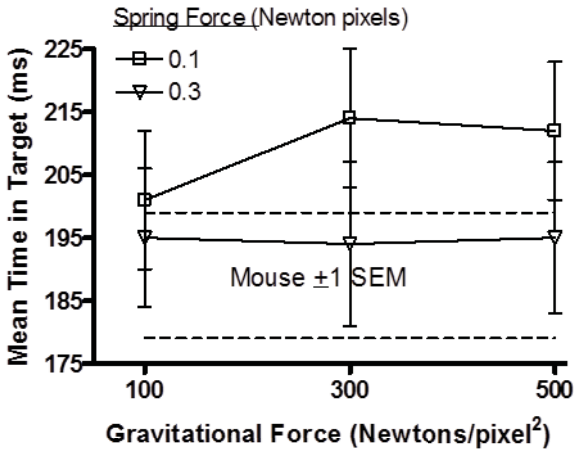
Results

- Time in Target
  - *Gravitational Force Level x Spring Force Level x Target Size*
    - For the 300 & 500 NPS Gravitational Force Levels, Spring Force Level only had a significant effect for *large* targets

Small Targets



Large Targets



Discussion

- Approach Time was shown to be a negatively accelerating function of Gravitational Force Level
  - *300 NPS reduced approach times by 14% when compared to the 100 NPS Gravitational Force Level*
  - *500 NPS, by contrast, only reduced approach times by 18% when compared to the 100 NPS Gravitational Force Level*
    - A slight improvement over the 300NPS level
- 300 NPS and 500 NPS were both shown to produce Approach Times similar to the computer mouse
  - *Note that participants had no prior experience with the Novint Falcon*

Discussion

- Spring Force Level was found to only have a main effect on Time Inside Target
  - *Consistent with Akamatsu and MacKenzie (1996), the stronger Spring Force Level reduced selection times*
  - *The stronger Spring Force Level also reduced Time Inside Target to a level comparable to the mouse for large targets at the higher Gravitational Force Levels*
    - Suggests higher Gravitational Force Levels may need a stronger Spring Force Value to keep the participant within the target's boundaries

Design Implications

- Results suggest future CDTI designs can utilize a lower level of gravitational force (i.e., 300 NPS)
  - *Will allow for more operator control over the device*
    - May mitigate the negative effects of target distractors
  - *The 300 NPS level did not require the higher spring force level (as seen with 500 NPS)*
- Lack of training with Spring & Gravitational force levels highlights the substantial benefit of force feedback
  - *Led to comparable performance to the much more familiar computer mouse*

Limitations

- Novint Falcon is not intended for use in commercial cockpits
  - *Future studies will need to incorporate a greater number of input devices*
- No baseline condition (i.e., no force feedback) for Novint Falcon
  - *Rorie et al. (2012) demonstrated ineffectiveness of Falcon without force feedback*

Questions?